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DEVICE AND PROCESS FOR THE REMOVAL OF MATERIAL FROM A SUBSTRATE
[Einrichtung und Verfahren zum Abtragen von Material von einem Substrat]

Raimund Hibst, et al.

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INVENTORS	(72):	HIBST, RAIMUND; SCHRÖDER, DIRK; BACHMANN, WERNER; STEINER, RUDOLF,
APPLICANT	(71):	FOUNDATION FOR LASER TECHNOLOGIES IN MEDICINE AT THE UNIVERSITY OF ULM,
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Description

This present invention concerns a device for removing material from a substrate, comprising a laser which transmits rays to a working plane intersecting the optical axis of the laser in which a section to be processed of the substrate can be arranged, as a result of which the material absorbing the rays is heated and evaporated or separated by mechanical means.

Additionally, this present invention concerns a process for removing material from a substrate wherein laser rays are aimed at a segment of the substrate to be processed, and the material absorbing the rays is heated and evaporated or separated by mechanical means.

Such a prior art device and/or process is used to remove layers of material, e.g. of organic tissue such as cornea of the eye, cartilage, or bone tissue. Plastics and other organic substances which absorb rays, e.g. IR rays, can also be used.

As a result of this absorption of rays, the irradiated material is heated beyond its boiling point and evaporated or separated by mechanical means under the influence of energy. Favorable efficiency is achieved in case the spectrum of the rays emitted by the laser is adjusted in accordance with the absorption spectrum of the material. For example, for the IR range of the spectrum, water represents an important absorber. In case a water-containing material, e.g. organic tissue, is irradiated with the energy-rich laser rays, in some areas of the irradiated area, the heat-sensitive material can dehydrate during the removal process. In particular, on the surface of the zone exposed

through removal such partial dehydration may occur. Dry islets are formed which, as surface irregularities, can cause negative effects.

In case the exposed surface is subjected to further irradiations, the islets are not sufficiently heated due to a lack of water and, consequently, a lack of absorption capacity and consequently not removed; the islets even increase in size and become harder. As a result, after the removal process is completed, an irregular surface is obtained which adversely impacts the desired success. For example, during removal of the cornea of the eye to correct ametropia, the tissue islets formed in the process can reduce the optical quality of the eye lens. In addition, in the vicinity of the tissue islets, the remaining tissue is damaged by heat since the irregular surface causes a non-uniform distribution of the radiation energy.

The object of this present invention is to describe a device and a process for removing material from a substrate which permits the removal of material with a high degree of geometrical accuracy.

This object is met by a device of the type mentioned above with at least one spraying device, arranged at a distance from the working plane, which produces a continuous spray jet consisting of a liquid/gas mixture, and whose spray axis intersects with the optical axis of the laser in the working plane.

During operation of the device, the liquid/gas mixture of the spray jet hits the segment of the substrate to be processed, and precipitation of the liquid on the segment causes an accumulation of liquid. This accumulation is driven apart in particular by the subsequent gas part in the spray jet, as a result of which a flow film with a constant

thickness and with a controlled flow speed is formed in the area hit by the laser beam. The gas arriving afterwards also smoothes the surface of the flow film. Its surface has then a roughly optical quality that the laser beam can penetrate to the material without optical distortion.

Uniform removal of material is therefore ensured since across its diameter, the intensity profile of the laser beam is not altered by the flow film. According to this present invention, the segment to be processed is continuously moistened to effectively eliminate the risk of dehydration of individual spots of the segment and therefore the formation of islets as well as damage to the remaining material. The surface of the substrate exposed after the removal of material is therefore free from surface irregularities. Any further removal of material performed after an initial removal step can be carried out with a high degree of geometric accuracy since a defined initial condition has been created. As a result, material can be removed within narrow, specified geometric limits while a high surface quality of the remaining surface is achieved.

In the easiest case, a spray can filled with gas and liquid and which produces a directional spray jet by means of a spray nozzle can be used as a spraying device. Additionally, pump-operated spraying devices can be used which operate like spray guns, e.g. those used for the application of paint.

In a preferred embodiment, the spraying device contains a ring nozzle comprising an inner nozzle tube, to which liquid can be supplied, as well as an outer nozzle tube arranged concentrically around the inner

nozzle tube, to which gas can be supplied in order to atomize the liquid.

This permits a separate supply of air and water to the outlet on the ring gap on the ring nozzle. The flow rates of gas and liquid can therefore be regulated independently from each other in a simple fashion.

In another embodiment, the average distance of the spraying device from the working plane and/or the angle of incidence of the spray jet onto the working plane can be adjusted.

This makes it possible to regulate the flow speed of the flow film, its position with respect to the segment to be removed, its surface, and thickness. These individual parameters are interrelated as described below: increasing the distance between the spraying device and the working plane leads to a decrease of the flow speed of the liquid in the flow film on the substrate, as a result of which the film thickness of the flow film increases. A flat angle of incidence increases the flow speed of the liquid/gas mixtures of the spray jet relative to the segment. As a result, the flow speed of the liquid in the flow film increases, which leads to a decrease in the thickness of the flow film. In addition to other optical characteristics of the substance of the liquid, the thickness of the flow film determines the radiation energy absorbed by it. Changing the film thickness of the flow film therefore makes it possible to control the radiation energy that reaches the substrate, and therefore the quantity of material removed by the laser.

In a preferred embodiment, several ring nozzles are provided which are arranged concentrically with respect to the optical axis of the

laser. As a result, the working plane in which the substrate is located is uniformly sprayed from several sources, creating a large surface with a homogeneous flow film on the segment to be processed. In this case, the spraying power of the individual ring nozzles can be small while the overall performance is high. Additionally, in another embodiment, the liquid and/or the liquid film of the segment contains a substance which scatters the laser rays.

As a result of this measure, the spatial stream profile of the laser beam is smoothed due to the scattering of light in the liquid/gas mixture of the spray jet or in the liquid film. The spatial intensity fluctuations across the diameter of the laser beam are smoothed. Because of the regular intensity pattern, the degree of accuracy in removing material can therefore be further increased. In addition, by means of the scattering substance, the absorbing molecules in the liquid film can be displaced, and the penetration depth of the rays can be increased.

One embodiment of this present invention is explained below by referring to the drawings attached hereto.

Figure 1 shows a partial schematic of a device for removing material wherein ring nozzles are arranged concentrically about a laser,

Figure 2 depicts the formation of a liquid film on the segment of a substrate, and

Figures 3a, and b are graphical representations of the spraying profiles of a laser beam across its diameter.

Figure 1 is a schematic representation of a device for removing material from a substrate according to this present invention. The optical axis 18 of a laser 12 intersects a working plane 14 at a right

angle. In the working plane 14, a segment 9 of a substrate 8 to be processed is arranged, e.g. the cornea of an eye. The laser 12 emits a laser beam 19 along the optical axis onto a segment 9. As a laser 12, a CO_2 laser, neodymium laser, thulium laser, holmium laser, or an erbium laser can be used. Preferably, as laser radiation, pulsed IR rays in the range between 1.3 to 15 μm are used, which is absorbed well by water. Typically, the diameter of the laser beam 19 is several mm, e.g. approx. 5 mm. This diameter, however, can be changed over a wide range by using optical attachments (not shown herein) and adjusted depending on the geometry of the substrate 8 and/or the areas to be removed.

Concentrically to the optical axis 18, several ring nozzles 20 of a spraying device 10 are arranged, two of which are shown in Figure 1. The ring nozzles 20 are supplied with air 34 from an air pressure vessel 26 and from a pressurized liquid container 28 with water 36. Instead of water 36, a NaCl solution may also be used.

The control valves 30, 32 are used to adjust the flow rates per time unit of the water 36 and/or the air 34 that are supplied to the ring nozzles 20 independently from each other. Each ring nozzle 20 produces a continuous spray jet 22, whose spray axis 16 intersects the optical axis 18 of the laser 12 in the working plane 14. The spray jets 22 are cone-shaped, and their cone angle 24 is adjusted to the surface of the segment 9, as a result of which, in the range of the incident rays of the laser beam 19, a sufficient supply of the air/water mixture is guaranteed.

Figure 2 shows further details of the device depicted in Figure 1; for illustration purposes, only one single ring nozzle 20 is shown. The

ring nozzle 20 consists of an inner nozzle tube 38 to which water 36 is supplied under pressure. The inner nozzle tube 38 is surrounded by an outer nozzle tube 40 with a tapered front segment 41. To the space formed between the inner nozzle tube 38 and the outer nozzle tube 40, air 34 is supplied under pressure. As soon as the air 34 leaves the ring gap 42 between the nozzle tubes 38, 40, the pressure energy of the air 38 is converted to speed energy: the air 34 relaxes and swirls the water jet leaving the inner nozzle tube 38 and creates the spray jet 22, which consists of a fine mixture of water drops 45 and air 34.

The spray jet 22 hits the surface of the substrate 8, which also comprises the segment 9 of the cornea to be processed. The water drops 45 precipitate on the surface of the substrate 8 and form an accumulation of water 44. As water 36 and in particular air 34 continues to flow, the water in the accumulation of water 44 flows outwards with respect to the fixed surface of the substrate 8 at a certain flow speed.

In the area of the intersection of the spray axis 16 with the surface of the substrate 8, a flow film 46 therefore forms, which completely covers the segment 9. This flow film 46 is homogeneous, i.e. it forms a continuous layer of liquid; its film thickness is largely constant. The surface of the flow film 46 is smooth, and its macroscopic form corresponds to the shape of the surface of the substrate 8. The incident laser beam 19 is therefore not optically distorted by the flow film 46.

The thickness and dimension of the water film 44 can be adjusted by specifically changing the angle of incidence of the spray jet 22 onto the segment 9 by changing the distance between the ring nozzle 20 and

the segment 9 as well as by modifying the pressure or the flow rates of water 36 and air. The flow speed of the water film 44 is largely determined by the flow speed of the air 34 in the spray jet 22. Increasing the distance between the ring nozzle 20 and the segment 9 as well as decreasing the air pressure causes a decrease in the flow speed of the air 34. As a result, the flow speed of the water film 44 is also reduced. A small outflow of water 34 leads to an increase in the thickness of the water film 44. Additionally, increasing the quantity of water 36 supplied per time unit, as a result of which the spray jet 22 receives more water drops 45, leads to an increase in the thickness of the water film 44.

By adjusting the aforementioned parameters, layers with a thickness ranging from 1 to 50 μu can be produced which are at least roughly constant throughout the segment 9 to be processed. Only outside of the segment 9, in the positions 48, swirls occur as the water 34 runs off. These swirls, however, do not adversely impact the removal of material since they occur outside of the range of the laser beam 19.

While removing material, the laser 12 emits one or several radiation pulses with a high energy density onto the segment 9. In the process, the laser beam 19 passes the water film 44 and partially penetrates the substrate 8 in the dotted area 50. In this location, the material is heated and evaporated or separated by mechanical means as the radiation energy is absorbed. Since the water film 44 continuously rinses the material to be removed, no dry islets can form in the area 50. The material is therefore removed in a geometrically accurate manner, depending on the spatial intensity profile of the laser beam 19.

The surface remaining after the material is removed is smooth and regular; any heat-induced damage of this surface is reduced.

This makes it possible to use a very energy-rich laser beam 19, as a result of which each laser pulse removes a high quantity of material. As a result, for example, the number of laser pulses required to remove cornea tissue to correct the ametropia, i.e. several hundred pulses with conventional devices, can be reduced to approx. 1 to 5 pulses. As a result, the patient's eye is impacted to a lesser degree, and the risk of incorrect pulses, which increases as the number of pulses increases, is significantly reduced.

A scattering medium is added to the water 36. As the laser beam 19 passes the spray jet 22 and the flow film 46 as shown in Figure 2, the rays are scattered on the scattering medium. Local intensity peaks of the laser beam are smoothed in the process. Across the diameter of the laser beam 19, the energy of the rays is balanced out.

This effect is explained below in Figures 3a, b. Figure 3a shows the intensity of the laser beam 19 along its diameter d. In reality, the intensity pattern is not smooth, but rather wavy due to a lack of homogeneity of the electric field distribution in the laser. As material is removed, existing intensity peaks 60 cause undesired superficial roughness on the remaining surface.

Figure 3b shows the intensity pattern of the laser beam 19 after passing a water film enriched with a scattering medium. The waves of the radiation intensity are smoothed out through scattering. Such a beam profile ensures a geometrically accurate removal of material and produces smooth surfaces.

Claims

1. A device for removing material from a substrate, comprising a laser which transmits rays to a working plane intersecting the optical axis of the laser in which a section to be processed of the substrate can be arranged, as a result of which the material absorbing the rays is heated and evaporated or separated by mechanical means, wherein at least one spraying device (10, 20) arranged at a distance from the working plane (14) is provided which produces a continuous spray jet (22) consisting of a liquid/gas mixture whose spray axis (16) intersects the optical axis (18) of the laser (12) in the working plane (14).

2. A device according to Claim 1 wherein the spraying device (10) contains a ring nozzle (20) having an inner nozzle tube (38), to which the liquid (36) can be supplied, as well as an outer nozzle tube (40), arranged concentrically around the inner nozzle tube (38), to which gas (34) can be supplied in order to atomize the liquid (36).

3. A device according to Claim 1 or 2 wherein the flow quantity per time unit of the liquid (36) which can be supplied to the inner nozzle tube (38) can be adjusted and preferably ranges from 0.1 to 5 ml/min.

4. A device according to one of the preceding Claims wherein the flow quantity per time unit of the gas (34) which can be supplied to the outer nozzle tube (40) can be adjusted and preferably ranges from 0.5 to 20 l/min, preferably between 2 and 10 l/min.

5. A device according to one of the preceding Claims wherein the spray jet (22) has a conical shape with a cone angle (24) in the range between 3° and 20°.

6. A device according to one of the preceding Claims wherein the average distance between the spraying device (10, 20) and the working plane (14) and/or the angle of incidence of the spray jet (16) onto the working plane (14) can be adjusted.

7. A device according to one of the preceding Claims wherein several ring nozzles (20) are provided which are arranged concentrically to the optical axis (18) of the laser (12).

8. A device according to one of the preceding Claims wherein the laser (12) emits IR rays in the wavelength range between 1.3 to 15 μm.

9. A device according to one of the preceding Claims wherein a CO_2 laser, a neodymium laser, a thulium laser, a holmium laser, or an erbium laser is used as a laser (12).

10. A device according to Claim 9 wherein the laser (12) is a pulse laser.

11. A process for removing material from a substrate in which the rays of a laser are aimed at a segment of a substrate to be processed, and the material absorbing the rays is heated and evaporated or separated by mechanical means, wherein the segment (9) of the substrate (8) is coated with a liquid film (44, 46) during irradiation.

12. A process according to Claim 11 wherein the liquid film (44, 46) flows with a prespecified speed with respect to the substrate (8).

13. A process according to Claim 1 or 2 wherein the rays of the laser (12) are pulsed.

14. A process according to one of the preceding Claims wherein the film thickness of the liquid film (44, 46) in the segment (9) of the substrate (8) to be processed is roughly constant.

15. A process according to Claim 14 wherein the film thickness ranges from 1 to 50 μm, preferably from 4 to 15 μm.

16. A process according to one of the preceding Claims wherein the liquid film (44, 46) consists of water (36) or a NaCl solution.

17. A process according to one of the preceding Claims wherein the liquid film (44, 46) contains a substance scattering the rays, preferably small balls made from latex or polystyrene, whose diameter is preferably equivalent to the wavelength of the laser radiation used.

18. A process according to one of the preceding Claims wherein for the removal of biological material, the liquid film (44, 46) contains a pharmaceutical agent, preferably an antibiotic, anesthetic, and/or mydriatic.

19. A process according to one of the preceding Claims wherein the temperature of the liquid film is roughly the same as the temperature of the substrate (8) and/or in the range between 0° and 35° C, preferably in the range between 5° C and 20° C.

20. A process according to one of the preceding Claims wherein the substrate (8) contains water with a concentration ranging 2 to 90 percent by volume.

21. A process according to Claim 10 wherein the substrate (8) is a biological substance, preferably organic tissue, in particular cornea, bone, or cartilage tissue.

Figure 1

Figure 2

Figure 3